

1.1 Epitaxy

The research in the Epitaxy Department is based on molecular-beam epitaxy (MBE) and is directed at two complementary tasks. On the one hand, our contribution to the overall research of the institute is the fabrication of custom-designed nanostructured samples. On the other hand, the growth mechanisms themselves are investigated, both for their own scientific sake and in order to optimize properties that are investigated in the other departments of the institute. The long tradition for the fabrication of two-dimensional heterostructures based on III-V semiconductors has recently been extended to research on the self-organized growth of nanowires for both arsenides and nitrides. Furthermore, ferromagnet-semiconductor hybrid systems for spintronic applications such as Heusler alloys grown on GaAs and, as a new project, Fe grown on GaN are investigated. As a distinctive experimental feature, three MBE chambers are located at the synchrotron BESSY of the Helmholtz Center Berlin for Materials and Energy and allow in-situ, real-time analysis by x-ray diffraction for various material combinations. In general, experiments are complemented by ab initio calculations.

The fabrication of GaAs/(Al,Ga)As quantum wells of extremely high quality has been an important output of MBE for more than two decades. As a new direction, such quantum wells are investigated by μ -photoluminescence as part of scrolled structures based on (In,Ga)As stressor layers [R. Hey *et al.*, J. Cryst. Growth **311**, 1680 (2009)]. In that case, the strain within the layer stack varies from compressive to tensile depending on the position in growth direction within the rolled-up structure. Consequently, the strain-induced red-shift depends on the z -position of the quantum well. In agreement with calculations, we found that the valence band has a mixed heavy-hole/light-hole character.

In the field of ferromagnet-semiconductor hybrid heterostructures, a high-quality interface between the two dissimilar materials is imperative. To this end, it is crucial that chemical interface reactions are avoided, both during growth but also during subsequent high-temperature processing steps. We investigated the thermal stability of epitaxial Fe films on GaN(0001) [C. X. Gao *et al.*, Appl. Phys. Lett. **95**, 111906 (2009)]. The morphology, crystal quality, and magnetic properties do not degrade during annealing up to 700 °C. Thus, this material system satisfies most requirements for device processing.

A significant advantage of nanowires over other nanostructures such as quantum dots is that both axial and radial heterostructures can be fabricated. Hence, an entire device structure can be created within a single nanowire. As a first step toward the introduction of spin-dependent functionalities into nanowire devices, we have grown semiconductor-ferromagnet GaAs-MnAs core-shell nanowire heterostructures [M. Hilse *et al.*, Appl. Phys. Lett. **95**, 133126 (2009)]. The MnAs shell forms by direct deposition on the nanowire sidewalls, and the crystallographic c -axis, i. e. the magnetic hard axis, is oriented along the nanowire axis.

Surface reconstructions on GaSb(001) were studied both experimentally and by ab-initio calculations. In-situ surface x-ray diffraction confirmed the $\beta(4\times 3)$ structure, but showed that

the Sb-rich (1×5) reconstruction differs from the previously proposed model [B. P. Tinkham *et al.*, *J. Electron. Mater.* **37**, 1793 (2009)]. Using density functional theory, a large variety of existing and new models for the (2×10) and $c(2 \times 10)$ reconstructions has been investigated [O. Romanyuk *et al.*, *e-J. Surf. Sci. Nanotech.* **7**, 429 (2009)]. None of these structures is thermodynamically stable, which suggests that the experimentally observed phases are kinetically stabilized. For the (4×3) periodicity, several reconstructions have been found that are thermodynamically stable for different surface stoichiometries [O. Romanyuk *et al.*, *Phys. Rev. B* **79**, 235330 (2009)]. Very importantly, these results imply the occurrence of one-dimensional disorder that explains the apparent contradiction in unit cell symmetry observed by scanning tunneling microscopy and by diffraction techniques.

With the aim of finding suitable high- κ gate dielectrics, both Pr_2O_3 and Gd_2O_3 were epitaxially grown on Si(001) [T. Watahiki *et al.*, *J. Vac. Sci. Technol. B* **27**, 262 (2009) and *J. Cryst. Growth* **311**, 2179 (2009)]. For Gd_2O_3 , the formation of a silicide at the interphase can be avoided by carefully adjusting both the growth temperature and the oxygen partial pressure. At the same time, a high level of crystallinity is achieved.

Particularly pioneering is our research on the epitaxy of Ge-Sb-Te phase-change memory alloys [W. Braun *et al.*, *Appl. Phys. Lett.* **94**, 041902 (2009) and R. Shayduk *et al.*, *J. Cryst. Growth* **311**, 2215 (2009)]. Although already in commercial use, the details of the structural changes that enable the memory functionality are still not clear. Compared to conventional polycrystalline sputtered films, high-quality epitaxial layers will enable a more comprehensive characterization of the structural phase change. We have identified a narrow temperature range near 190 °C, in which epitaxial films of $\text{Ge}_2\text{Sb}_2\text{Te}_5$ with a cubic structure are obtained on GaSb(001). Laser-induced switching in such samples has been verified by Raman measurements.